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(54) Battery recharging system with signal-to-noise responsive falling voltage slope charge termination.

(57) The falling voltage slope charge termination routine is performed during intervals of the charging cycle in which signal-to-noise ratio is comparatively high. The falling voltage slope charge termination technique is automatically disabled or rendered less sensitive to noise during times when the signal-to-noise ratio is comparatively low. In this way, accurate charge termination is accomplished without error otherwise induced by voltage noise during charging. The charge termination technique responds quickly to a charged battery indication, since signal averaging to negate the effects of noise can be minimised or eliminated.

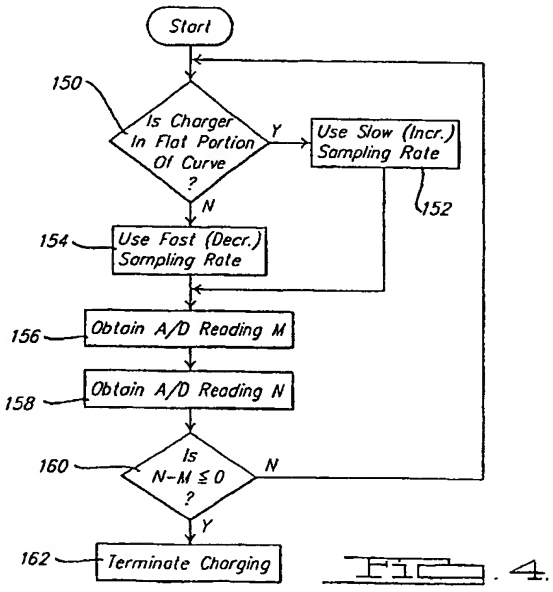

Fig. 4.

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The present invention relates generally to rechargeable batteries and to electronic circuits for charging rechargeable batteries.

Rechargeable batteries have become quite popular for use in electronic equipment, power tools, portable computers, cordless phones, children's toys, and the like. Virtually every user of rechargeable batteries wants the ability to recharge as quickly as possible. In addition, some users like the convenience of being able to leave a rechargeable battery in the charger at all times, so that a fully charged battery will always be available. To accommodate the former requirements, there are a number of quick-charging battery chargers available. To accommodate the latter, there are a number of trickle charging battery chargers available.

Whether the battery charger is designed as a quick-charger or as a trickle charger, it is highly desirable to avoid overcharging. Overcharging produces undesired heating and high pressures which can physically and chemically alter the cells of the battery and degrade the battery's capacity to hold charge. This problem is particularly prevalent when quick-charging battery chargers are used. Quick-charging battery chargers typically deliver a high charging current which can rapidly overheat the battery unless the charging current is terminated or greatly reduced once the fully charged condition is reached.

Determining precisely when to terminate the high charging current is not simply a matter of sensing when the battery voltage reaches a fully charged level. In most batteries the voltage rises in a nonlinear way as charging current is applied, and it is often difficult to accurately sense or predict when the fully charged voltage is reached.

The applicant has devoted a considerable effort in analyzing the voltage characteristics of rechargeable batteries as charging current is applied. It is now known that the battery voltage increases over time as charging current is applied and that the voltage-time curve exhibits various inflection points where the slope or first derivative of the voltage-time curve actually changes from positive to negative or from negative to positive. The US Patent Nos 4,388,582 and 4,392,101, (Saar et al) describe these inflection points in conjunction with a rapid charging system for rechargeable batteries.

Although the inflection point analysis technique described in these patents has been widely successful, there is still interest in further improvement. Today this Saar technique is frequently implemented using microprocessor or microcontroller circuitry which periodically samples the battery voltage during charging and uses that sample data to perform an inflection point analysis. Analog-to-digital converters are used in sampling the battery voltage data and converting that data into digital values which the microprocessor manipulates. The Assignee's current technology uses logarithmic analog to digital converters for this purpose.

Inasmuch as the sampled voltage data is already being obtained for use by the Saar inflection point analysis technique, that data can also be used to perform other charge termination techniques. One such technique is the negative slope technique which seeks to terminate charging current when the slope of the voltage-time curve becomes negative. The falling slope technique can be used in place of the Saar inflection point technique or it can be used to augment the Saar technique. One problem with the falling voltage or negative slope technique is that it can be quite sensitive to noise. Noise is particularly troublesome in the flat regions of the voltage-time curve, since a momentary drop in voltage due to noise can be misinterpreted as a falling voltage or negative slope.

The present invention solves the noise problem by automatically changing the effective sampling rate during the flat region of the voltage-time curve to obtain higher noise immunity. Modulation of the sampling rate to improve the noise immunity may be effected by sensing the slope of the voltage-time curve and automatically decreasing the sampling rate when the shallow portion of the curve is reached. In accordance with the present invention, a method for charging a battery comprises the steps of: supplying charge current to the battery; measuring the slope of the battery voltage verses time curve to determine when the supplying of charge current to the battery should be terminated; obtaining battery voltage data during the measuring step at a first sampling rate in a first time interval when the slope of the voltage curve exceeds a predetermined value; and terminating the supplying of charge current when the slope of the battery voltage curve is not positive; characterised by: obtaining battery voltage data during the measuring step at a second sampling rate less than the first sampling rate in a second time interval when the slope of the voltage curve is less than the predetermined value. According to one embodiment of the invention, the first sample rate is effectively decreased to the second sample rate by switching off the termination step during the second time interval when the slope of the voltage curve is less than the predetermined value (i.e., corresponding to the flat region). Turning off the charge termination routine in this fashion has the effect of increasing the sampling interval to a time longer than the flat portion of the curve. Thus any noise-induced falling voltage fluctuations during this interval are ignored.

The first embodiment of the present invention solves the aforementioned problem associated with the falling voltage slope termination technique by automatically disabling that technique when the signal to noise ratio is poor (i.e. when the voltage-time curve is comparatively flat). At other times, the falling voltage slope technique is enabled, allowing the battery

charging to be terminated when the battery achieves full charge and the voltage begins to drop. In this way, the falling voltage slope technique can be used in conjunction with the Saar inflection point technique or as a replacement for it.

According to a second embodiment, the first sample rate may be decreased to the second sample rate by storing the voltage data in a data structure (e.g, a microprocessor memory stack) and by selective manipulation of the data stored in the data structure. Using this technique, samples of the battery voltage are continually taken at predetermined intervals and stored on the stack. A slower sampling rate is effected during the flat portion of the curve by using every other stored value, every third stored value, every fourth stored value, and so forth, to achieve the desired sampling rate modulation. If desired, adjacent stack values can be averaged thereby further mitigating the effects of noise.

The first time interval may correspond to a predetermined percentage of an approximate time required to fully charge a fully discharged battery. The predetermined percentage is preferably about 15%.

The invention will now be described, by way of example only, with respect to the accompanying drawings, in which:

Figure 1 is an exemplary voltage-time charging curve for a nickel cadmium battery showing exemplary inflection points at A and B;

Figure 2 is a schematic block diagram showing the major operational and control circuitry of a fast battery charging system;

Figures 3A - 3C (collectively referred to as Figure 3) illustrate the stack data structure of one embodiment of the invention;

Figure 4 is a flowchart illustrating a presently preferred charge termination procedure in accordance with the present invention;

Figure 5 is a flowchart illustrating an alternate charge termination procedure in accordance with the present invention; and

Figure 6 is an adaptive embodiment of the invention.

The following description of the preferred embodiments concerning fast battery charging is merely exemplary in nature and is in no way intended to limit the invention or its application or uses.

As disclosed in US 4 388 582 and US 4 392 101, a typical voltage-time curve of a charging sequence of a nickel cadmium (NiCad) battery is shown in Figure 1. It is noted that the discussion herein is directed to charging a single battery; however, it is equally applicable to a series of batteries as would be found in a battery pack. As the battery is being charged, the voltage continuously rises as indicated by the curve until it reaches a desirable maximum charge point. Although the specific values of the curve may differ from battery to battery, the general shape of the curve is typical for all nickel cadmium batteries. Likewise, each other type of rechargeable battery known in the art will have a typical voltage-time curve indicative of its type and, as such, the process discussed below is applicable to any of these other types.

As shown, the voltage-time curve can be separated into at least four distinct regions. Region I represents the beginning of the charging sequence just after the battery is initially attached to the charger and the charging begins. This region is represented by a dotted line due to the fact that the voltage characteristics in this region are somewhat unreliable and may vary from battery to battery in accordance with its prior history of being charged and discharged and its present state of discharge. Additionally, this region is of little importance in the charging sequence since it is generally traversed within a relatively short period of time (usually between 30 to 120 seconds) after the start of the charging sequence.

After the charging sequence passes through region I, the charging curve will enter the more stable region II. Region II is generally the longest region of the charging sequence, and is marked by most of the internal chemical conversion within the battery itself. Because of this, the voltage of the battery does not substantially increase over region II, and thus, this region represents a plateau region in the charging curve. At the end of region II is an inflection point A in the curve. Inflection point A represents a transition from region II to region III, and is noted by a point where the slope of the curve changes from a decreasing rate to an increasing rate.

Region III is the region in which the battery voltage begins to increase rapidly with respect to time, thus representing a region of rapid voltage rise. As the battery voltage increases through region III to its fully charged condition, the internal pressure and temperature of the battery also increases. When the effects of temperature and pressure within the battery begin to take over, the increase in battery voltage begins to taper off. This tapering off effect is noted as inflection point B and is also characterised by the sharp fall in the voltage derivative curve dV/dt.

Region IV represents the fully charged region between the inflection point B and including charge termination target represented by point C. The charging voltage only stabilizes at point C for a very short period of time. Consequently, if charging continues, the additional heating within the battery will cause the voltage of the battery to decrease and in addition may cause damage to the battery.

US 4 388 582 and US 4 392 101 disclose a method of analysing the battery voltage versus time-charging curve by detecting the inflection points in the curve in order to determine the appropriate time to terminate the fast charge process. By measuring the slope of the charge curve at a predetermined sampling rate, it is possible to first determine inflec-

tion point A and then begin looking for inflection point B. Since the sampling period is constant, the calculation of the slope is merely a subtraction of the most recent voltage sample from a previous voltage sample. However, once the occurrence of inflection point B is detected, the battery voltage is actually beyond inflection point B. Thus, by terminating charging upon the detection of the second inflection point B, the battery voltage is actually at a point approximated by point C on the curve when charging is discontinued. Accordingly, it will be appreciated that this charge control procedure avoids overcharging of the battery into region IV of the curve.

The basic circuit components operable to be used in an inflection analysis fast battery charger will first be discussed. It is noted that these components are illustrated by way of a nonlimiting example as other circuit configurations will be equally applicable. Turning to Figure 2, a half bridge-type power supply circuit **10** is shown in a block circuit diagram. Circuit **10** includes a high voltage input circuit **12** for supplying high voltage to some components of the circuit **10**, a low voltage power supply circuit **14** for supplying a low voltage supply to other components of the circuit **10**, a pulse width modulation oscillator circuit **16** for generating a high frequency output to be used as a control input for the high voltage circuit **12**, a constant current supply circuit **18** for providing a constant current supply to a battery **22** to be charged, and a charge current monitoring circuit **20** for monitoring the charge current rate of the battery **22** and for providing a feedback signal to the pulse width modulation circuit **16** to desirably vary the control signal provided to the high voltage circuit **12**. A microcomputer **24** is incorporated for controlling the charging scheme. Other circuit components of the circuit **10** include an optional temperature check circuit **26** which monitors the temperature of the battery **22**, and a digital display circuit **30** for providing an indication to the operator of the various parameters of the charging process. Additionally, an analog-to-digital converter **28** is provided for converting the analog battery voltage signal from the battery **22** to a digital signal suitable for processing by the microcomputer **24**.

The high voltage circuit **12** receives a 120 volt alternating current (AC) generally from a standard outlet. The alternating input signal is rectified and filtered to produce a smooth DC voltage of approximately 150 volts. The AC input signal is also applied, through a transformer (not shown), to the low voltage supply circuit **14** along line **13**. The low voltage supply circuit **14** rectifies the AC signal and applies it to certain voltage regulator circuits (not shown) to provide regulated 5-volt and 15-volt outputs for the other circuit components. The various 5-volt and 15-volt supply lines to the other circuit components of the circuit have been omitted for clarity.

The pulse width modulator (PWM) oscillator circuit **16** receives a 15-volt signal from the supply circuit **14** along line **15** and provides a pulsed frequency signal, generally in the form of a square wave, along line **17** to the high voltage circuit **12**. The square wave signal from the oscillator circuit **16** is provided through a coupling transformer (not shown) to a pair of power switching transistors (not shown) which, via conventional phase control techniques, regulate the amount of current supplied to the primary coil of the main step down transformer for each half cycle of the AC waveform. The step down transformer converts the high voltage signal on its primary coil to a low voltage, high current signal at its secondary coil and applies this signal to the constant current supply circuit **18** along line **19**. The duty cycle of the pulse width modulator signal from the oscillator circuit **16** thus controls the level of charging current applied to the battery **22**. The pulse width modulation approach minimizes the size of the step down transformer required to provide the necessary high current to the current supply circuit **18**. PWM oscillator circuit **16** also includes a soft start circuit (not shown) for gradually ramping up the duty cycle of the PWM oscillator circuit **16** when the charging sequence is initiated.

When the microcomputer **24** initiates a charging sequence by applying a signal on line **23** to the current supply circuit **18**, charge current is applied to the battery **22** through the low voltage constant current supply circuit **18** along line **21**. The current supply circuit **18** preferably includes a reverse polarity detection circuit (not shown) which protects the circuit **10** from damage in the event that the battery **22** is inserted backwards. The battery current is sensed along line **25** by charge current monitoring circuit **20**. If the charge current varies from the predetermined level, the charge current monitoring circuit **20** will provide an output on line **27** to the PWM oscillator circuit **16**. The PWM oscillator circuit **16** will then alter the duty cycle of the square wave signal to the high voltage circuit **12** in order to alter the current charge current appropriately. Likewise, at the end of the high current charging sequence, the microcomputer **24** produces an output signal on a charge/trickle line **29** to switch to a trickle charge mode.

The temperature check circuit **26** provides a circuit for monitoring battery temperature. The dotted line **31** from the temperature check circuit **26** represents a heat sensing device, such as a thermistor, that is physically located adjacent the position of the battery **22** when it is plugged into the charger to sense the temperature of the battery **22**. The temperature check circuit **26** determines when the battery temperature exceeds a predetermined threshold value and in such event sends a signal along line **33** to the microcomputer **24**. The microcomputer **24** then sends a signal on line **23** to halt the charging process.

In order to enable the microcomputer **24** to monitor the charging sequence to determine the inflection

points in the charging curve of Figure 1, it is necessary to convert the analog battery voltage signal to a digital signal. Therefore, an analog-to-digital converter **28** is incorporated. The analog-to-digital converter **28** receives the analog battery voltage on line **39** and produces a digital signal on line **37** which the microcomputer **24** uses to determine the battery voltage value. If desired, the digital signal may be in the form of a timing signal in which clock pulses are produced and counted to yield digital "count" values representing voltage.

Inflection points in the charging curve are determined by monitoring the slope of the curve (the first derivative or time rate of change of the curve) to detect when the slope reaches a minimum value or a maximum value; i.e., when the rate of change in the slope changes from a negative value to a positive value or from a positive value to a negative value. In practice, this is accomplished by taking the difference between successive voltage readings and by determining when the difference reaches a minimum or a maximum value.

With reference to Figure 1, it is seen that the voltage derivative curve dV/dt changes from increasing to decreasing at second inflection point B. Therefore, if the battery charging operation commences when the battery voltage is in Region I, the battery voltage will pass through both inflection points A and B. On the other hand, if the battery is already partially charged such that the battery charging operation commences in Region III, the A inflection point is never reached. In either case, however, the battery charging operation should be caused to terminate after the B inflection point is detected, as this represents the fully charged condition. Note that the battery voltage actually begins to fall off or drop shortly after the actual charge termination point C is reached. This region should therefore be avoided as this is the region in which overtemperature and high pressure conditions begin to manifest themselves.

The present invention allows a flat slope or negative slope charge termination system to be reliably implemented. The flat slope or minus slope system, referred to as "slope detection", can be used in conjunction with the Saar double inflection point analysis or as an alternative to it. The slope detection technique has been found to work particularly well with metal nickel hydride batteries.

Essentially, the slope detection technique looks for the point on the voltage-time curve at which the slope goes to zero (flat slope) or goes negative. Referring to Figure 1, it is seen that the slope dV/dt goes to zero at the peak voltage designated generally by reference letter P. Note that the point P is near, but not necessarily coincident with, point C. Recall that point C is the point at which the Saar double inflection point analysis actually terminates charging current. In practice, the precise Saar termination point C depends on the response time of the system and on the degree of digital filtering employed. In other words, point C occurs sometime after inflection point B has occurred and the system has had time to respond to its occurrence. Therefore, in actual practice, point P detected by the flat slope or zero slope technique and point C used in the Saar technique may be in fact coincident, or either point may occur slightly before the other. Thus the flat slope or minus slope detection mechanism can serve as a good backup system in the event the Saar system does not respond quickly enough for a given battery.

One difficulty with the flat slope or falling slope technique is encountered in the flat region of the curve designated generally by II in Figure 1. Metal nickel hydride batteries are less prone to difficulty in this region because the voltage-time curve of such batteries rises more steeply than the curve of the illustrated nickel cadmium battery. While, in fact, the slope of the voltage-time curve is rising in region II, as evidenced by the positive first derivative dV/dt, the voltage is not rising very rapidly. Thus, it is possible for spurious noise fluctuations to produce a false trigger in this region. Note in Figure 1 there is a slight perturbation designated generally at X which is indicative of the type of noise fluctuations which can occur. If one of these perturbations were to appear as a zero slope or falling slope (dV/dt 0), the flat slope or falling slope termination technique would cause premature termination of the battery charging current.

To combat this problem, the present invention employs a sampling rate modulation technique or a slope detection disabling technique which both ensure that the readings taken during the flat portion of the curve do not produce false triggering. These techniques can be implemented in different ways. Several will be illustrated here.

One technique for producing sampling rate modulation is to perform the modulation digitally by stack manipulation. The stack manipulation technique takes advantage of the fact that current-day charge termination routines for implementing the Saar technique use a stack-like data structure for storing, averaging and processing the digitally sampled voltage readings.

Referring to Figures 3A - 3C (collectively referred to as Figure 3), the stack-like data structure is illustrated at **100**. The presently preferred embodiment employs a data structure capable of storing eight digital values supplied by analog-to-digital converter **28**. As each sample is taken by the analog-to-digital converter, the corresponding digital value is pushed onto stack **100** so that it occupies location AD_0. By this action, the previously existing AD_0 is pushed down to location AD_1; AD_1 is pushed down to AD_2; and so forth. At the opposite end of the data structure the terminal value AD_7 is simply discarded as diagrammatically illustrated by bit bucket **102**. This data structure is

used in implementing the Saar technique. This same data structure may also be used to implement the flat slope or negative slope detection technique. In this regard, both the Saar technique and the slope detection technique derive values which reflect the slope of the voltage-time curve.

By way of illustration, refer to Figure 3A which illustrates how all eight values stored on stack **100** may be processed and used to produce a slope reading. As diagrammatically illustrated, the newest four values on the stack are added together; similarly the oldest four values are added together. The resulting sums M and N, respectively, are subtracted to yield a value N - M indicative of slope. In this regard, slope will be understood as the time rate of change in the voltage (dV/dt). Since the sampling rate is known, and in this case constant, the resulting N - M difference is indicative of slope.

The slope detection termination technique monitors the slope value N - M. When that value becomes zero or goes negative, termination of the charging current is triggered.

Basing the slope detection technique on the cumulative effect of eight samples may not be fast enough in practice to prevent overcharging. The presently preferred embodiment takes voltage samples every 16 seconds. Thus by subtracting groups of four numbers, the detection scheme lags by 4 x 16, or 64 seconds. This time lag may be too long to avoid overcharging.

Figure 3B illustrates a stack manipulation technique whereby this 64-second time lag can be cut in half. In Figure 3B pairs of digital values are added together and then subtracted, as illustrated. In Figure 3B values AD_0 and AD_1 are added together as intermediate value M and values AD_2 and AD_3 are added together as intermediate value N. The intermediate values are subtracted, as before, to arrive at a slope reading. Since groups of two readings are used instead of groups of four, the time lag is reduced to 2 x 16, or 32 seconds.

For even quicker response time, Figure 3 illustrates two individual readings AD_0 and AD_1 used directly to produce the slope reading. In this case, since individual readings are used directly, the slope value lags only 16 seconds.

With the foregoing in mind, it will now be better appreciated how a spurious voltage reading can produce a false termination. When the signal processing illustrated in Figure 3A is used, a single erroneously low reading will not affect the outcome. This is because the single reading is, in effect, averaged with three other readings which were all taken at different times. Thus the averaging effect of the processing illustrated in Figure 3A renders it unlikely that a false termination will occur.

Contrast this with the processing illustrated in Figure 3C. Here, two individual readings are used to produce the slope value. An erroneous reading can, therefore, produce a false indication that the slope has gone zero or negative.

The present invention automatically modulates the effective sampling rate to produce fast response time when the signal-to-noise ratio is high and to average out or ignore local voltage perturbations when the signal- to-noise ratio is low. One embodiment for accomplishing this is illustrated in Figure 4. In Figure 4 a test is performed at step **150** to determine whether the charger is operating in the flat portion of the voltage-time curve represented by the region II in Figure 1. If so, at step **152**, the effective sampling rate is modulated to employ the highly averaged, comparatively slow responding sampling technique of Figure 3A. On the other hand, if the charger is not operating in the flat region of the curve, control proceeds to step **154** where a faster acting, less averaged sampling technique is used, such as the technique of Figure 3C (or optionally the technique of Figure 3B).

Next, in steps **156** and **158** two consecutive readings M and N are taken. Then, in step **160**, if N - M is less than or equal to zero, charging is terminated at step **162**. Otherwise, control branches back to step **150**, as illustrated. There are several ways to determine if the battery charger is operating in the flat portion of the curve. One way is to monitor the individual voltage readings. If the individual readings are below a threshold value, then it can be assumed that the charger is operating in the flat portion of the curve. Another technique is simply measuring the elapsed time that the battery charger has been operating. In most cases, the battery charging curve is sufficiently stable such that it can be assumed the charger is in the flat portion of the curve after an elapsed of about 15% of the full charging cycle.

An alternative embodiment of the invention is illustrated in Figure 5. As will be seen, in this embodiment the slope detection technique is disabled when the charger is operating in the flat portion of the curve. Referring to Figure 5, analog to digital readings are employed at steps **200** and **202** to obtain successive readings N and M, each indicative of battery voltage at different points along the voltage-time curve. Next, in step **204**, these values are compared, such as by subtracting N - M to determine if the slope of the curve has gone to zero (flat) or gone negative. If not, then the routine simply branches back to step **200** where the above process is repeated. On the other hand, if the slope has gone to zero or gone negative control proceeds to step **206** where a determination is made whether the charger is currently in the flat portion of the curve. This can be done using any of the techniques described above in connection with Figure 4. If the charger is in the flat portion of the curve, control simply branches back to step **200** where the above steps are again repeated. In other

words, in the flat portion of the curve a negative slope or zero slope is simply ignored. On the other hand, if at step **206** the charger is not in the flat portion of the curve, then control proceeds to step **207** where a flag is tested to determine whether the slope was previously falling. If so, then charging is terminated at step **208**. If not, step **209** is performed to set the flag, so that the next flat slope or falling slope condition will cause charge termination. Thus the routine of Figure 4 provides additional filtering by requiring two detections of a flat slope or falling slope before charge termination is triggered. Naturally, this filtering technique can be expanded to require more than two slope detections, if desired. This filtering technique can also be used in the other embodiments described above.

Upon reflection it will be seen that causing the result of step **204** to be ignored at step **206** has the effect of decreasing the sample rate to a period longer than the period of region II (Figure 1) of the curve. Stated differently, the results of data obtained during region II of the curve may be effectively ignored by extending the sampling rate so that no samples are produced during the region II period.

The above-described techniques for modulating the sampling rate to block the effects of noise in the flat portion of the curve are static techniques, in that a predetermined sampling rate modulation technique is employed automatically when the flat region of the curve is reached. If desired, the modulation technique can also be employed dynamically, where the degree of sampling rate modulation is actively selected based on the sensed signal-to-noise ratio. One embodiment of such a dynamic technique has been illustrated in Figure 6. In Figure 6, the slope of the battery voltage is compared to several predetermined levels at steps **250**, **252**, and **254**. Based on this comparison, the appropriate sampling rate is selected in steps **256**, **258**, and **260**, respectively. These different sampling rates could be effected using the stack manipulation techniques illustrated in Figures 3A - 3C. For example, for low slopes the technique of Figure 3A could be used for sampling rate #1. For intermediate slopes the sampling rate technique of Figure 3B could be used for sampling rate #2. For higher slopes the sampling technique of Figure 3C could be used for sampling rate #3.

After the appropriate sampling rate has been selected, the appropriate readings are taken at steps **262** and **264** to obtain the values M and N. Using the stack-like data structure illustrated in Figures 3A - 3C, these M and N values can simply be obtained by selecting the appropriate numbers from the stack. Once obtained, the M and N values are compared at step **266**, whereupon charge termination is triggered at step **268** if the slope (N - M) is zero or negative. Otherwise, control branches back to the starting point where the above procedure is repeated.

The embodiment of Figure 6 thus dynamically selects the appropriate sampling rate based on actual measured conditions. While a simple slope measurement has been used in steps **250**, **252**, and **254**, other suitable techniques can also be used.

From the foregoing it will be understood that the present invention provides a mechanism to allow slope detection techniques to be employed, either individually, or in conjunction with other techniques, such as the Saar technique. The invention solves the problem of false triggering due to noise in the flat regions of the voltage-time curve. Therefore, the invention is most advantageous when used with batteries such as nickel cadmium batteries, which exhibit portions of relatively flat slope.

While the invention has been described in connection with the presently preferred embodiment, it will be understood that certain modifications can be made to the illustrated embodiment without departing from the spirit of the invention as set forth in the appended claims.

Claims

1 A method for charging a battery (22) comprising steps of:

supplying (18) charge current to the battery;

measuring (160; 204; 266) the slope of the battery voltage verses time curve to determine when the supplying of charge current to the battery should be terminated;

obtaining battery voltage data (156, 158; 200, 202; 262, 264) during the measuring step at a first sampling rate (154; 204, 206; 256, 260) in a first time interval when the slope of the voltage curve exceeds a predetermined value; and

terminating (162; 208; 268) the supplying of charge current when the slope of the battery voltage curve is not positive; characterised by:

obtaining battery voltage data (156, 158; 200, 202; 262, 264) during the measuring step at a second sampling rate (152; 204, 206; 258) less than the first sampling rate in a second time interval when the slope of the voltage curve is less than the predetermined value.

2 A method according to Claim 1 characterised in that the first sample rate is effectively decreased to the second sample rate by switching off (206) the terminating step during the second time interval when the slope of the voltage curve is less than the predetermined value.

3 A method according to Claim 1 characterised in that the first sample rate (154; 256, 260) is decreased to the second sample rate (152, 258) by storing the voltage data in a data structure (100) and by selective manipulation of the data stored in the data structure.

4 A method according to Claim 1 characterised in

that:

a predetermined charging time indicative of the approximate time required to fully charge a fully discharged battery is established and

said first time interval is a predetermined percentage of said charging time.

5 A method according to Claim 4 characterised in that said predetermined percentage is on the order of about 15 percent (15%).

6 A method according to Claim 1 characterised in that said first time interval is established adaptively based on said data of battery voltage.

7 A method according to Claim 1 characterised in that said second time interval is established adaptively based on said data of battery voltage (150; 206).

8 A method according to Claim 1 characterised in that the second time interval is terminated when said battery voltage is above a predetermined voltage.

9 A method according to Claim 1 characterised in that battery voltage data is obtained during the measuring step at a third sampling rate (154; 204, 206; 260) faster than the second sampling rate (152; 204, 206; 258) in a third time interval when the slope of the voltage curve exceeds the predetermined value.

10 A method according to Claim 9 characterised in that the first and third sample rates are equal.

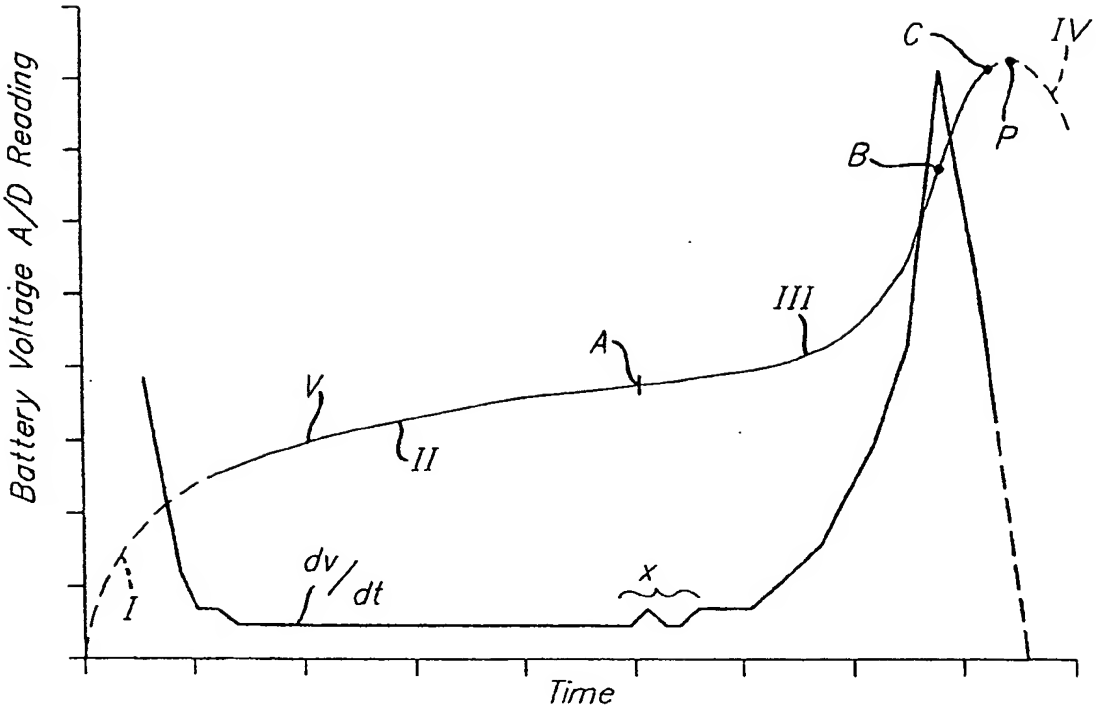

Battery Voltage A/D Reading
Time
C
IV
P
B
III
A
V
II
I
dv
dt
x

FIG. 1.

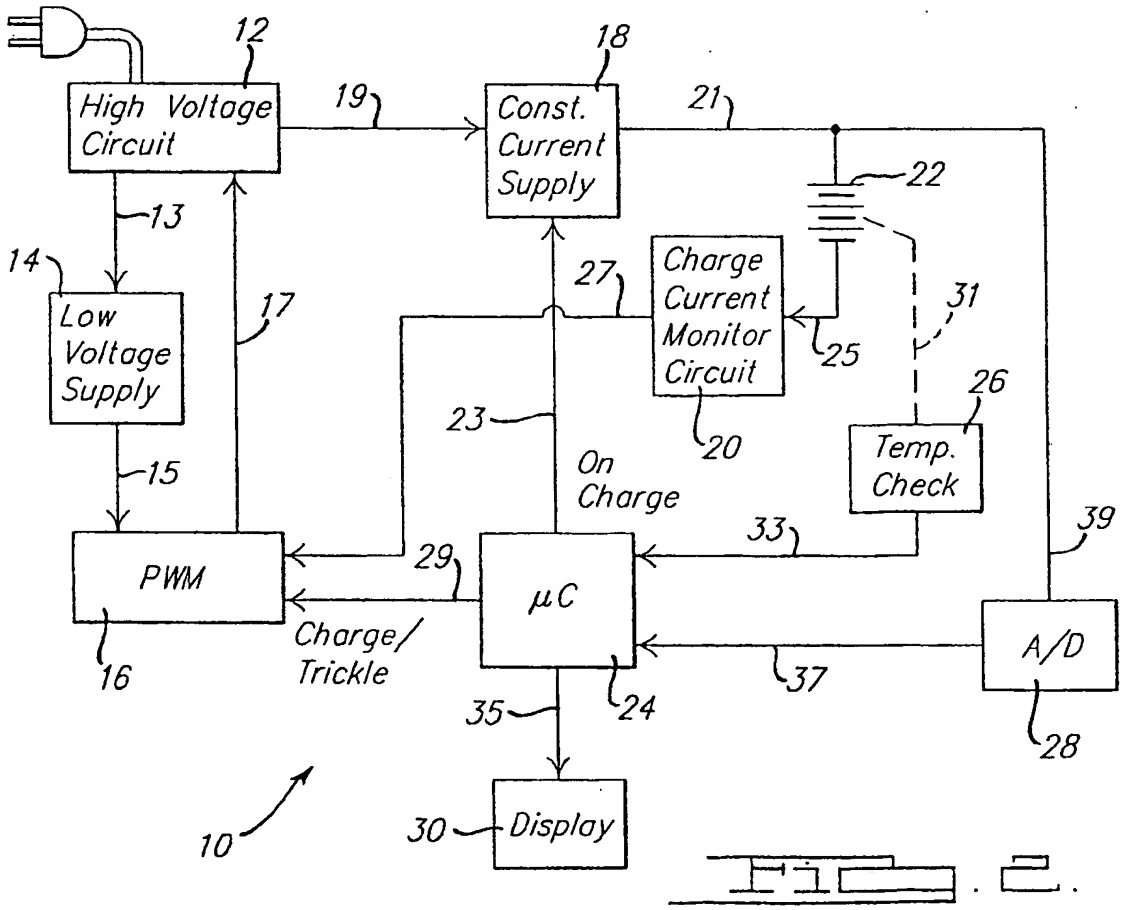
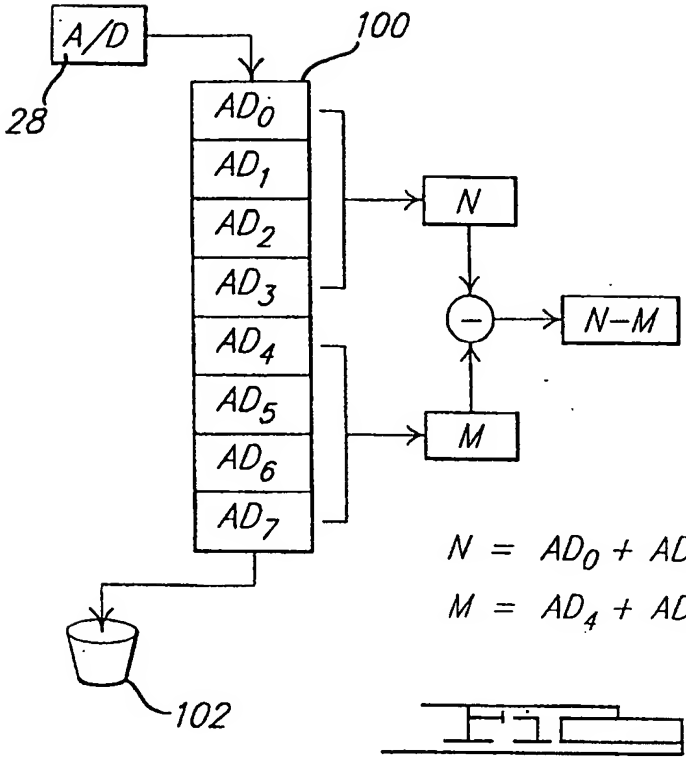

12
High Voltage Circuit
19
18
Const. Current Supply
21
22
13
14
Low Voltage Supply
17
27
Charge Current Monitor Circuit
25
31
26
23
20
Temp. Check
On Charge
15
33
39
PWM
29
µC
A/D
Charge/ Trickle
16
37
24
28
35
10
30
Display

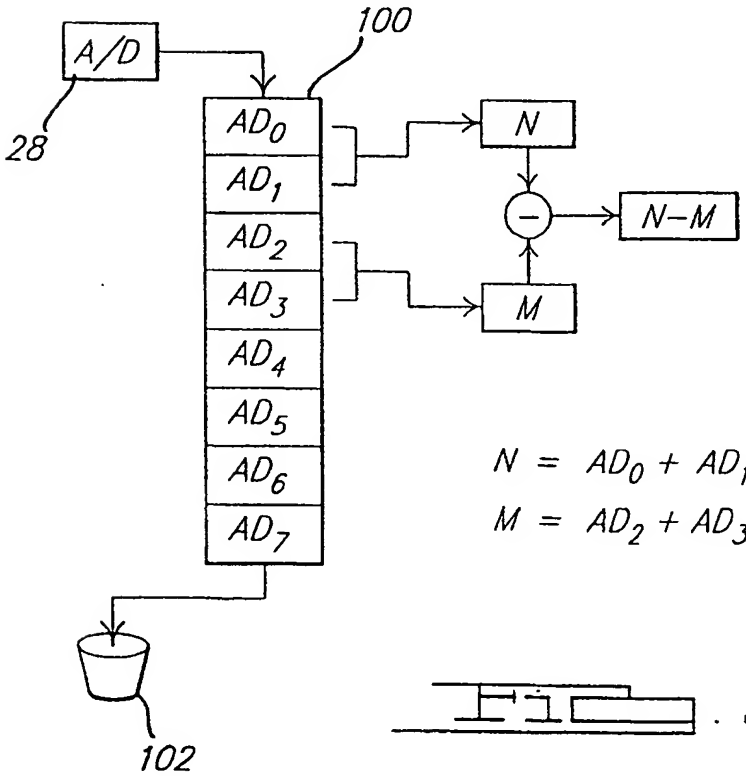
FIG. 2.



$N = AD_0 + AD_1 + AD_2 + AD_3$

$M = AD_4 + AD_5 + AD_6 + AD_7$

Fig. 3A.



$N = AD_0 + AD_1$

$M = AD_2 + AD_3$

Fig. 3B.

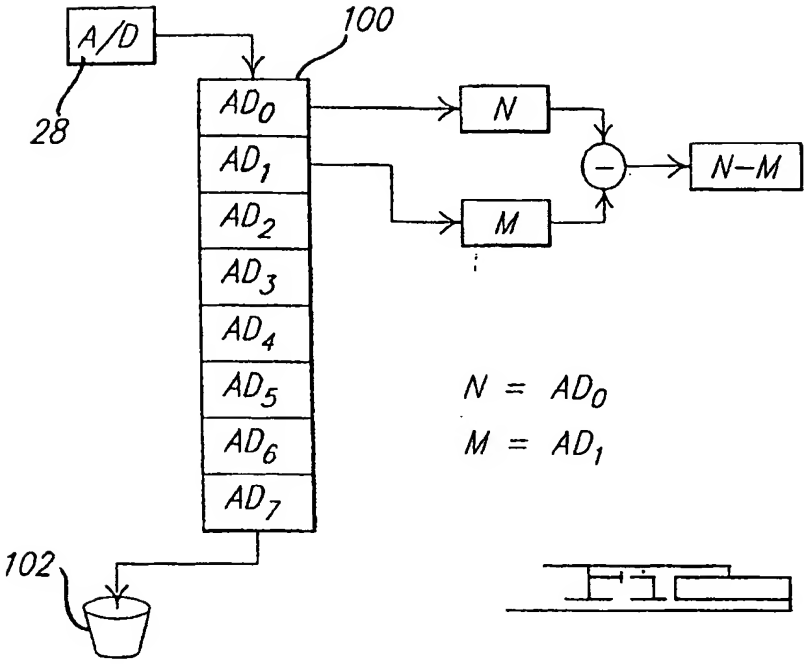

A/D
28
100
AD0
AD1
AD2
AD3
AD4
AD5
AD6
AD7
N
M
N-M
N = AD0
M = AD1
102

Fig. 3C.

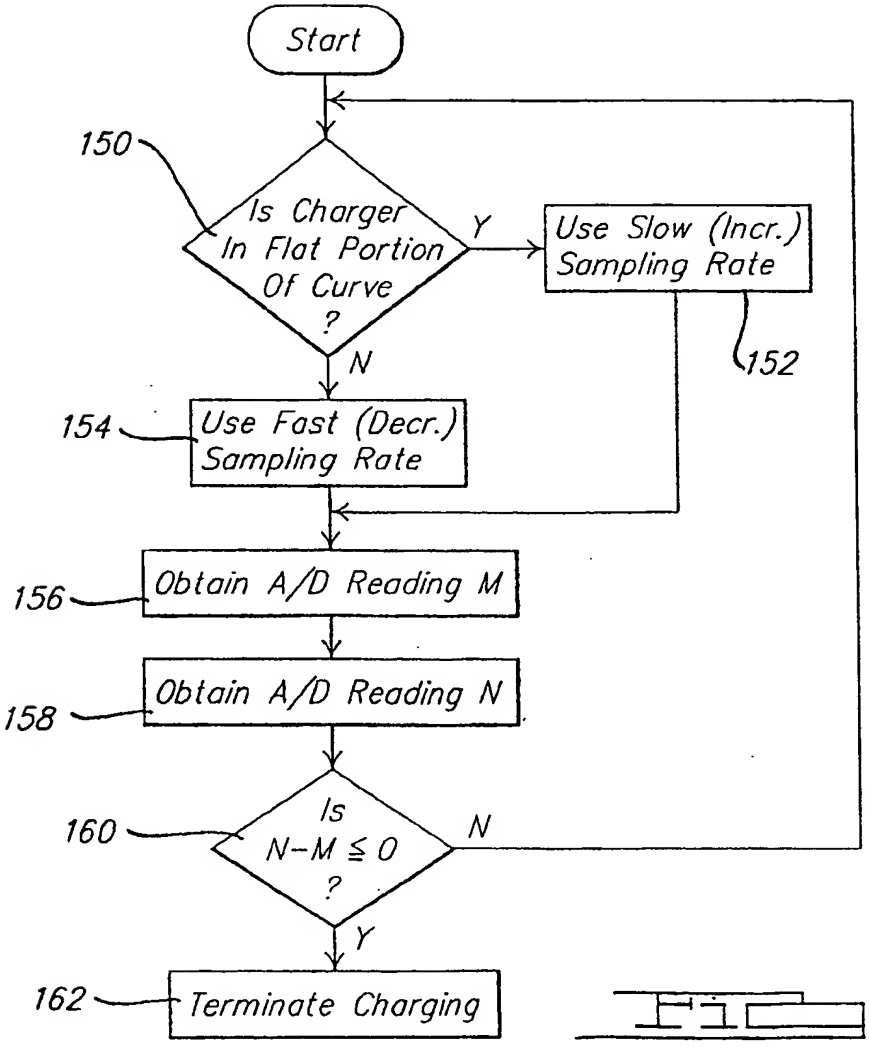

Start
150
Is Charger In Flat Portion Of Curve ?
Y
Use Slow (Incr.) Sampling Rate
152
N
154
Use Fast (Decr.) Sampling Rate
156
Obtain A/D Reading M
158
Obtain A/D Reading N
160
Is N-M ≤ 0 ?
N
Y
162
Terminate Charging

Fig. 4

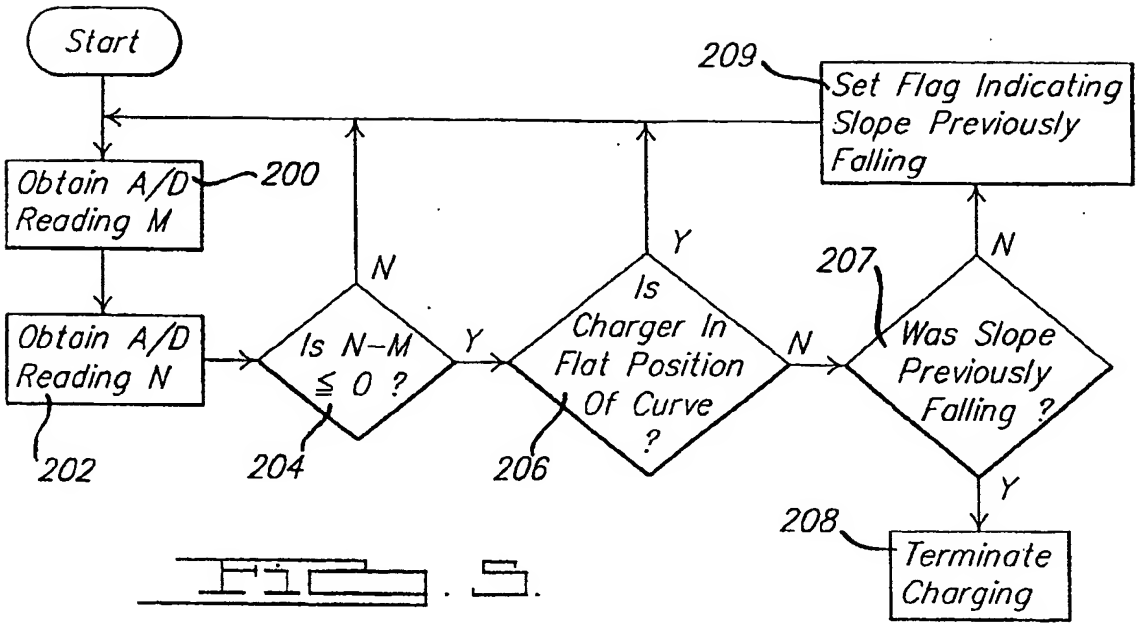

Start
Obtain A/D Reading M
200
Obtain A/D Reading N
202
Is N−M ≦ 0 ?
204
N
Y
Is Charger In Flat Position Of Curve ?
206
Y
N
Was Slope Previously Falling ?
207
N
Y
Set Flag Indicating Slope Previously Falling
209
Terminate Charging
208

Fig. 5.

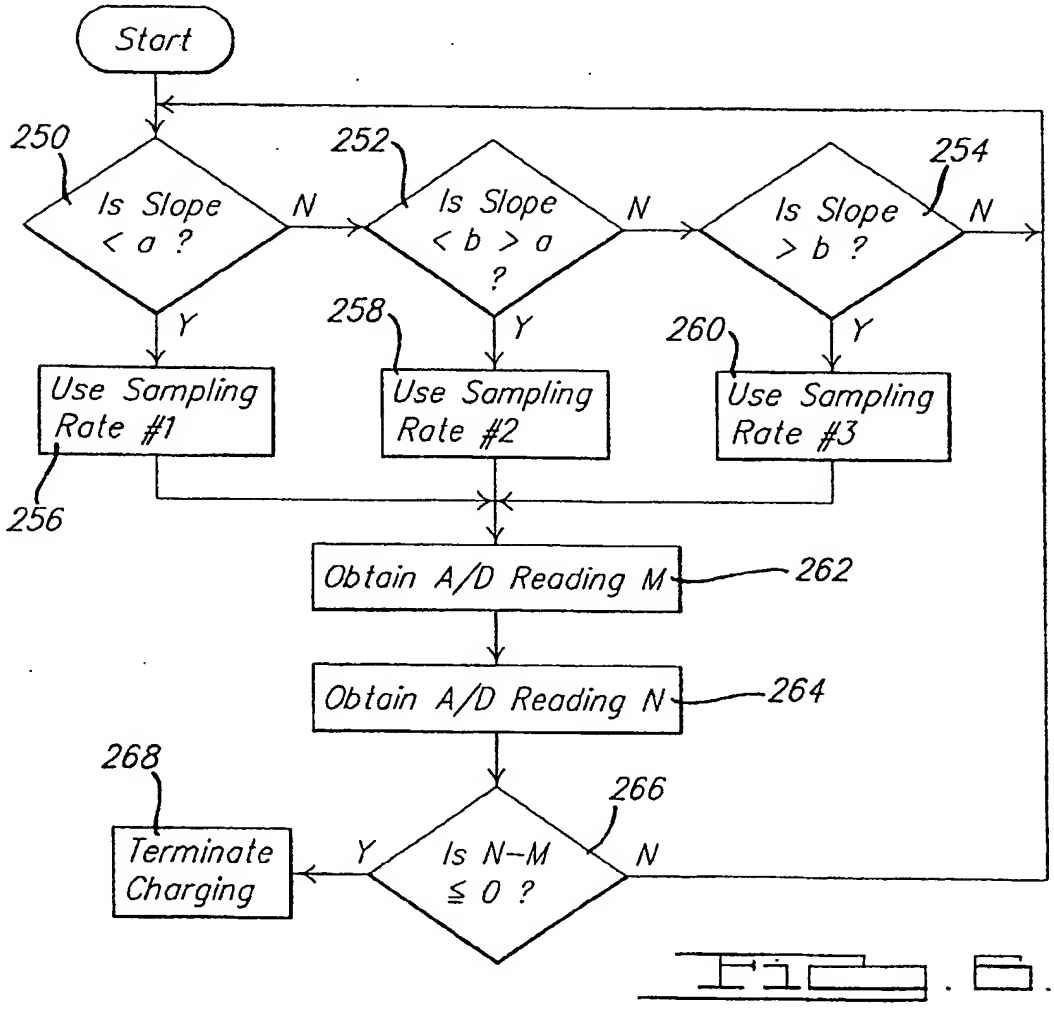

Start
Is Slope < a ?
250
N
Y
Use Sampling Rate #1
256
Is Slope < b > a ?
252
N
Y
Use Sampling Rate #2
258
Is Slope > b ?
254
N
Y
Use Sampling Rate #3
260
Obtain A/D Reading M
262
Obtain A/D Reading N
264
Is N−M ≦ 0 ?
266
Y
N
Terminate Charging
268

Fig. 6.

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 30 1237

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	US-A-5 268 630 (P.BHAGWAT ET AL) * the whole document *	1	H02J7/10
A	EP-A-0 580 300 (SANYO ELECTRIC CO) * column 5, line 36 - column 8, line 9 *	11	
A	WO-A-88 05222 (HM ELECTRONICS) * claim 1 *	1	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6) H02J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	7 June 1995	Kelperis, K

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
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